Testing bespoke management of foraging habitat for European Turtle Doves *Streptopelia turtur*

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Total word count: 8,407 words

Title word count: 12 words

Abstract word count: 402 words

Abbreviations:	AES	Agri-Environment Scheme
	ES	Environmental Stewardship
	HLS	Higher Level Stewardship
	ELS	Entry Level Stewardship
	GLMM	Generalized Linear Mixed-effects Model

Running head: Testing vegetation structure and seed provision

Abstract

Agri-environment schemes (AES) are increasingly being employed to mitigate against biodiversity loss in agricultural environments. The European Turtle Dove *Streptopelia turtur* is an obligate granivorous bird in rapid decline within both the UK (-96% since 1970) and across continental Europe (-77% since 1980), despite widespread uptake of AES. Here, we assess the efficacy of a potentially new, sown agri-environment option designed to provide abundant, accessible seed for *S. turtur* during the breeding season. During summer 2011 we compared vegetation structure and seed provision on trial plots to control habitat types (existing agri-environment options thought to potentially provide *S. turtur* foraging habitat) to assess whether trial plots performed better for foraging *S. turtur* than control habitats. In September 2011 all trial plots were topped (cut) and half of a subset of trial plots were then scarified (60% of soil surface disturbed). Vegetation structure on topped, and topped and scarified trial plots was measured during summer 2012 to determine which management regime was most effective in maintaining suitable sward structure and seed provision into the second year. No control habitat type produced as much seed important in *S. turtur* diet as trial plots at any point during year one. Trial plots provided accessible vegetation structure early in the season with no difference in vegetation metrics between trial plots and previously published data on *S. turtur* foraging locations. However, to allow later access, management is required during mid-June to open up the sward through localized topping or scarification. Vegetation structure during year two was generally too dense to attract foraging *S. turtur*. However, scarifying trial plots during the September following sowing encouraged self-seeding of *Fumaria. officinalis* (a plant species historically forming a significant proportion of *S. turtur* diet during the breeding season) into the second year, with this species present in 16% of scarified

trial plots compared to only 4% of topped trial plots during year two. Thus, autumn scarification, possibly followed by topping or scarification of part of the trial plots in June, is necessary for trial plots to provide more seed and access for *S. turtur* than existing agri-environment options during year two. We recommend modifications to our original seed mix in order to reduce vegetation density and improve vegetation structure. The study provides an example of the need to strike the right balance between food abundance and accessibility, through vegetation structure, when designing agri-environment scheme management options that provide food for birds.

Keywords: agri-environment; arable plant; *Fumaria officinalis*; seed plot; farmland management; food abundance; food accessibility; vegetation management

Introduction

Agricultural intensification over recent decades has been linked to declines in farmland wildlife, as agricultural efficiency and productivity have increased to feed a growing human population (Donald et al. 2001, Robinson and Sutherland 2002, Reidsma et al. 2006). In recent decades, agri-environment schemes (AES) have been increasingly utilised to mitigate farmland biodiversity declines across Europe and North America. However, the impacts of most of these schemes on widespread species have been modest or mixed (Kleijn et al. 2006, Birrer et al. 2007). Some of the strongest evidence of AES reversing declines involve range-restricted bird species, e.g. *Emberiza cirlus* (Peach et al. 2001) and *Tetrax tetrax* (Bretagnolle et al. 2011), when subject to much higher levels of targeting and advisory support than that available under standard AES (Perkins et al. 2011), but population-level benefits are not apparent for most widespread bird species (e.g. Davey et al., 2010).

As of February 2014, 57 % of English farmland was managed under Entry Level Stewardship Agreements, with a further 14 % managed under Higher Level Stewardship Agreements (Natural England 2014); despite this, the UK population of *S. turtur* has declined by 95 % since 1970 (Eaton et al., 2013). This is paralleled by a 75 % decline across Europe since 1980 (PECBMS 2012). As the species is a long-distance migrant, it is possible that carry-over effects from wintering grounds or migration may have contributed towards the decline (e.g. Norris & Marra, 2007; Eraud et al., 2009). However, factors operating on the breeding grounds are thought, at least in part, to be driving the UK population trend: evidenced by the fact that the number of breeding attempts per pair has halved since the onset of the decline (Browne and Aebischer 2004). Nesting habitat is thought unlikely to be limiting, as nesting areas previously utilized by *S. turtur*, in which habitat has not altered, are no longer used due to a reduced density of breeding birds (Dunn & Morris, 2012). Over the same time-scale as the population decline, *S. turtur* has shown a dietary switch from the seeds of wild plants typical of arable fields to anthropogenic sources of cereal grain and oilseed rape (e.g. following harvest operations or as spills in farmyards), reflected in the diet of both adults and nestlings (Browne & Aebischer, 2003a), while territories have been lost from areas with less bare ground and fallow (Dunn and Morris 2012); traditionally, habitats rich in arable plants. This suggests that a reduced availability of arable plant seeds has led to an increased reliance on anthropogenic food resources, especially early on in the breeding season (Browne and Aebischer 2003a).

S. turtur is ecologically unique in Europe, being the only Afro-Palearctic migrant that is an obligate granivore, and in the UK, with the exception of *Carduelis cannabina*, the only species reliant upon seed food throughout the annual cycle (Wilson et al., 1996). Other dove and pigeon species have more generalist diets, taking invertebrates and green plant matter when seed availability is low (Murton et al., 1964). The reduction in the availability of seeds from arable plants has been largely driven by the susceptibility to herbicides (Marshall et al., 2001; Moorcroft et al., 2006) and the switch to autumn sown crops, which has reduced the amount of overwinter fallow for arable plants to mature and, in the case of *Fumaria officinalis*, a plant historically important in *S. turtur* diet (Murton et al. 1964), has also reduced tillage during the peak germination period in the spring. The switch in *S. turtur* diet may have additional implications: wheat is generally considered a low-quality diet for columbiformes (e.g. Costantini, 2010) and this switch may have contributed to the truncation of the breeding season (Browne and Aebischer 2003b). Diet quality can have knock-on effects on a range of ecological traits (e.g. sexually selected traits

(Meadows et al., 2012), clutch size (Vergauwen et al., 2012), and survival (Browne et al., 2006)), and the nutritional implications for *S. turtur* of this dietary change are unknown. A more direct result of the change in *S. turtur* feeding ecology might be an increased risk of transmission of disease: *Trichomonas gallinae*, a protozoan parasite directly transmitted at food and water sources, has been found at very high prevalence in *S. turtur* and in grain piles and water on UK breeding grounds (Lennon et al., 2013), and confirmed as likely cause of death in both adult and nestling birds (Stockdale et al., in press). Thus, without stringent hygiene precautions, the option of supplementary feeding by providing seed in piles or via hoppers has the potential to increase parasite transmission and, alone, is unlikely to provide a satisfactory solution for this species. The provision of sown or naturally regenerating semi-natural foraging habitat in close proximity to nest sites (crucial to minimize energetic costs to breeding adults) is therefore likely to be key conservation measure for the species on its UK breeding grounds.

Current English agri-environment options deliver nesting habitat for *S. turtur* through management of hedgerows, scrub and orchard under Environmental Stewardship (ES) management, but options providing semi-natural seed food resources are limited. Baker et al. (2012) found a positive localized population response to arable margins (an amalgam of several different option types), but many of these margin management options often result in a relatively tall, dense sward that is unlikely to be used by foraging *S. turtur*, which prefer relatively open foraging sites with sparse vegetation cover (Murton et al., 1964; Browne & Aebischer, 2003a). In the ES AES in England, uncropped, cultivated margins (primarily designed to benefit arable plants) and the addition of wildflowers to field corners and buffer strips may be better suited to the requirements of foraging *S. turtur*, but they have low uptake, e.g.

due to perceived or actual problems with pernicious weeds on some soil types, or high costs of establishment and management to maintain the correct sward structure. Although many European AES contain rotational fallow options, the withdrawal of the set-aside scheme funded under Pillar One of the Common Agricultural Policy and other economic drivers, has led to a Europe-wide reduction in the amount of fallow available (Morris et al., 2011), further reducing the area of potentially suitable foraging habitat for *S. turtur*.

Here, we describe a two-year trial of a sown seed mix designed to provide an accessible source of seed for *S. turtur* throughout the breeding season. We used 29 trial plots across six farms to address the following questions:

1. How do the *S. turtur* trial plots compare to existing AES options in providing a source of accessible seed food during the first year after sowing?

2. Which management (scarification or topping in the autumn of the first year) is more successful at continuing the provision of accessible seed into the second year, and how does this compare to existing AES options that may provide food for *S. turtur*?

3. How do trial plots compare to previously published data documenting vegetation structure of foraging locations used by *S. turtur*?

Methods

Site selection

Six trial plot farms were selected during summer 2010, according to the presence of at least two pairs of territorial *S. turtur* within a 1 km^2 consisting mostly of ‘typical’ arable land, with no more than 5 % land currently under seed-rich non-cropped management such as wild bird seed mix or fallow. Between two and seven (mean ± 1 SE: 5.67 ± 0.4) trial plots covering two ha in total were sown on each farm (except one farm where trial plots only covered 1 ha), giving a total of 29 trial plots; trial plots ranged in size from 0.063 to 1.178 ha (mean ± 1 SE: 0.301 ± 0.046 ha). Six control farms were within 26 km (mean ± 1 SE: 11.84 ± 3.15 km) of their corresponding trial plot farm and selected on the same basis, but with no trial intervention: ideally control farms would have been within 10 km of their respective trial farm, but we were restricted by low *S. turtur* numbers.

The trial plot seed mix (detailed in Table 1) consisted of plants known to be important in *S. turtur* diet (Wilson et al., 1996; Browne & Aebischer, 2003a), to provide seed throughout the *S. turtur* breeding season (May – September), and to be largely non-pernicious to cropping and thus acceptable to farmers. The mix was designed to last for at least two years, in order to encourage farmer uptake. Trial plots were sown at the rate recommended by the seed supplier (Kings of Holbeach) at 20 $kg.ha^{-1}$, intended to form a fairly sparse ground cover and ensure seed accessibility. The recommended sowing date for the mix was early – mid September; however, due to late seed delivery and subsequent wet weather the trial plots were sown between late September and mid November (five farms) and during March 2011 on the final farm due to wet ground conditions.

Trial Plot Management

During September 2011, following the first *S. turtur* breeding season, trial plots were assessed for structure and invasion by agriculturally pernicious weeds. Trial plots with low weed burdens that were unlikely to be exacerbated by the creation of sparsely vegetated swards (n=19 plots across five farms) were selected for further management trials. Farmers were requested to mow each selected plot, and then scarify half using a power harrow set to scarify 60 % of the plot to a depth of 2.5 cm during September 2011. However, two farmers (nine plots) misinterpreted these instructions and mowed the entirety of half the total number of plots (n=4), scarifying the entirety of the other half of the plots (n=5).

Control plot selection and plot measurements

During year one (2011), between two and six (mean ± 1 SE: 5.5 ± 0.34) control plots were selected on each trial and control farm, giving 66 control plots in total. Control plots were areas considered to form potential alternative *S. turtur* foraging habitats currently available on farms; either options in AES, or other naturally occurring areas or management practices outwith AES. They fell into the following categories (sample size in parentheses): meadow, defined as low-input grassland not cut for silage (seven), floristically enhanced margins (seven), grass margins including paths (17), nectar flower margins (five), wild bird seed mix (17), fallow including areas of failed or sparse crop, areas subsequently planted with vegetable crops, and nesting habitat for *Vanellus vanellus* (13). During year two

(2012), between two and four (mean ± 1 SE: 3.0 ± 0.4) control plots were selected on trial plot farms only. These consisted either of fallow controls (defined as an area where the ground had been disturbed during the previous autumn, and not since been cultivated; n=9) for scarified trial plot sections or second year or older nectar flower controls for mown trial plot sections (n=9), providing a total of 18 control plots in year two.

During 2011, measurements were taken from four points within each trial and control plot on three occasions (rounds) throughout the *S. turtur* breeding season, during mid-May, late June- early July, and late July-early August. During 2012, measurements were taken as for 2011, but on only two rounds during May and late June. Two points were 2 m from opposing edges of each plot; two were central at evenly spaced intervals. Points were selected semi-randomly on each occasion by throwing a 0.5 m square quadrat. The % bare ground (to the nearest %) within each quadrat was recorded by eye, along with maximum vegetation height at each point (the highest piece of vegetation touching a disc of 60 mm diameter placed at the central point of the quadrat; ± 1 cm): measurement of these two variables allowed a direct comparison with previous data from turtle dove foraging locations (Browne and Aebischer 2003a). Vegetation density was assessed at the central point of the quadrat to assess the likelihood of a foraging turtle dove accessing any seed present, using a drop-disc sward stick (disc diameter: 200 mm; disc weight 83 g) lowered gently on to the vegetation; the point at which the disc stopped was considered the density of the vegetation (± 1 cm). Vegetation cover was assessed to determine the visibility of potential predators by a foraging turtle dove using a Sigma fish-eye 180° lens attached to a Nikon D50 camera placed at the central point of the quadrat facing upwards. Images were analyzed subsequently to establish % vegetation cover using Gap Light

Analyzer (Frazer et al., 1999) version 2.0, with a blue color plane, and with the threshold manually adjusted to control for differing background light intensities.

To establish seed density, a standing seed sample was taken from a 20 x 20 cm square adjacent to each quadrat; standing vegetation rooted within the square was collected and frozen for subsequent analysis. The soil within the square was also collected to a depth of 0.5 cm and frozen for subsequent analysis of any fallen seed accessible to *S. turtur*. Subsequently, seed was extracted from standing seed and soil samples, separated according to species, identified to family level (or species level where possible) and dried in a 50 °C oven for at least 48 hours, allowing the calculation of dry seed weight of each species within each plot.

Seed weight constituted the dry weight of seeds known to be found in *S. turtur* diet as determined through previous dietary studies (Murton et al., 1964; Browne & Aebischer, 2003a; detailed in Appendix A), with the exception of grass. Whilst some grass species are eaten by *S. turtur* (Murton et al., 1964; Browne & Aebischer, 2003a), we did not identify grass seeds to species, although the majority of the vegetative grass seeds found within our trial plots were *Alopecurus myosuroides*. As *A. myosuroides* is not considered to be important in *S. turtur* diet (Appendix A), grass species were excluded from analysis.

At each trial plot point, the presence or absence of each sown species was recorded, along with vegetation cover of each on a three point categorical scale (1: <10 %; 2: 10-50 %; 3: >50 %). Any other species with greater than 5 % cover was also recorded for each quadrat to examine invasion by unsown plants.

Statistical analyses

Establishment

To determine whether sown species differed in establishment success between trial plots, species was included as a fixed effect in a generalized linear mixed-effects model (GLMM) with binomial error structures, with presence or absence from each point for each species during year one as the response variable. The analysis was carried out at the plot scale; thus Plot ID within Farm were included as nested random effects to control for pseudo-replication of multiple measures within plots and non-independence of plots on the same farms; Round was included as a fixed factor.

As sowing rate differed between species, establishment was also expected to differ, so the establishment of each species between plots was considered separately in subsequent analyses to determine whether establishment differed between rounds (time of year sampled), and between sowing periods, for both years one and two separately. For each species, a binomial GLMM was constructed with presence or absence at each point as the response variable. The minimal model contained just the nested random terms of Plot ID within Farm. Round (May, early July and July/August) and sowing date (Sep 2010, Oct 2010, Nov 2010 and Mar 2011) were tested separately against the minimum model and included when $p<0.1$. An interaction between round and sowing date was also considered.

Vegetation Structure and Seed availability

To determine how vegetation structure differed between trial and control plot habitats in year one, GLMMs were constructed with each of vegetation height, density, cover and % bare ground as the response variables, transformed where necessary to fit assumptions of either Poisson (vegetation height and density) or binomial (vegetation cover and % bare ground) error structure. As vegetation changed throughout the season, a separate model was run for each of the three survey rounds. Each model consisted of plot habitat, and nested random effects of Plot ID within farm to control for localized geographic and management effects. To determine whether trial plots produced more seed than control habitats, three Poisson GLMMs (one for each round) were constructed as described above with total seed weight (both fallen and standing) as the response variable. Post hoc contrasts (Crawley, 2007) were used to identify where any differences lay.

For year two data, three separate analyses were run, to determine a) whether vegetation structure and seed availability of mown and scarified trial plot sections differed, b) whether vegetation structure and seed availability of mown halves of trial plots differed from nectar flower controls, and c) whether vegetation structure and seed availability of scarified trial plots differed from fallow controls.

Comparison of trial plots during years one and two

To examine differences between trial plot structure and seed provision during years one and two, GLMMs were constructed as previously described. Each model consisted of year as a fixed factor, with nested random effects of trial plot ID within farm to control for localized geographic and management effects.

Comparison of trial plot vegetation structure to S. turtur *foraging sites*

To determine whether the vegetation structure within trial plots was significantly different from *S. turtur* foraging sites located during a previous intensive study (Browne & Aebischer, 2003a), we used the published mean, SE and sample size of both vegetation height (0.13 ± 0.01; n=114) and % bare ground (59.09 ± 4.41, n=114) of locations at which *S. turtur* individuals were observed feeding during 1998 – 2000. We compared Browne & Aebischer's (2003a) data from foraging locations to the vegetation height and % bare ground within our trial plots separately, during rounds 1, 2 and 3 of Year 1, and during rounds 1 and 2 of Year 2 in topped and scarified trial plot sections separately using t-tests. Our analysis assumed that feeding habitat preferences of this species have not changed during the previous 15 years.

Results

Trial plot establishment

During year one, establishment rates differed significantly between sown species at the plot scale (χ^2_5=795.61; p<0.001; Figure 2) with establishment in order of highest to lowest rate: *Trifolium pratense* > *T. repens* > *Vicia sativa* > *Medicago lupulina* > *Fumaria officinalis* > *Cerastium fontanum*. All species were influenced by the sampling round, with increased establishment as the season progressed for *T. repens*, *V. sativa*, *M. lupulina* and *T. pratense*, and decreased establishment for *F. officinalis* and *C. fontanum* (Figure 2; Full model results in Appendix B). Sowing date did not directly influence the establishment of any species but an interaction between round and sowing date influenced the establishment of *M. lupulina*, *F. officinalis*, *T. pratense* and *T. repens* (Figure 2). *M. lupulina* showed nil establishment early and late in the season in spring-sown trial plots and there was later establishment of *F. officinalis*, *T. repens* and *T. pratense* in spring-sown trial plots (very low establishment during May in spring-sown trial plots; Figure 2).

During year two, sampling round influenced the establishment of *T. pratense* only (full model results in Appendix C), with establishment lower during the second round than the first (Figure 3). Management marginally influenced the establishment of both *V. sativa* and *F. officinalis*, with marginally significant trends towards higher establishment of *V. sativa* in mown trial plot sections and higher establishment of *F. officinalis* in scarified trial plot sections (Figure 3).

Seed availability and vegetation structure

Direction and significance of differences in vegetation structure and seed availability between trial and control plots during year 1 are summarized in Table 3, with full model results and estimates given in Appendix D. No control habitat produced as much seed of plants known to be important in *S. turtur* diet than autumn-sown trial plots during any sampling period (Table 2). During May, vegetation structure was consistently favourable when compared to nectar flower margins, grass margins and meadow but unfavourable when compared to spring-sown trial plots and seedbeds for new wild bird seed mixes (Table 2). Mid- and late-season, vegetation structure was no better in autumn sown trial plots than any control habitat (Table 2).

In year two, Habitat only influenced a difference in seed availability in an interaction with round between scarified trial and fallow control plots (full model results in Appendix E), with seed availability on scarified trial plots increasing more than on fallow control plots between rounds (Figure 4a). Bare ground differed between all three habitat comparisons, although the apparent biological difference in round 1 was statistically only marginal between mown and scarified trial plots. Less bare ground was present on both trial managements than their respective controls, and there was marginally more bare ground on scarified trial plots than on mown trial plots (Figure 4b). Vegetation cover differed between both trial habitats and their respective control types, but an apparent biological trend between mown and scarified trial plots during round 1 was not statistically significant. Vegetation cover was higher on both trial habitats than on their respective controls (Figure 4c). Vegetation height and density differed only between scarified trial plots and fallow controls, with both measures higher on scarified trials than on fallow controls (Figures 4d & 4e).

Comparison between trial plots during years one and two

Vegetation height, density and cover were all higher during year two than year one (Height: $z_1=2.64$, $p=0.008$; Density: $z_1=3.24$, $p=0.001$; Cover: $z_1=2.80$, $p=0.005$; Figure 5). Bare ground was much reduced, but seed weight was greater during year 2 than year 1 (Bare ground: $z_1=-4.45$, $p<0.001$; Seed weight: $z_1=2.01$, $p=0.045$; Figure 5).

Comparison of trial plot vegetation structure to S. turtur *foraging sites*

Trial plot vegetation structure, in terms of vegetation height and % bare ground, was similar to previously assessed *S. turtur* foraging locations (Browne & Aebischer, 2003a) only early during Year 1 (round 1; Tables 3a & b). Scarified trial plots early in Year 2 had similar vegetation height (round 1; Table 3a) but significantly lower % bare ground (Table 3b). Trial plot structure at all other times was significantly different from foraging locations (Tables 3a & 3b).

Discussion

The rapid decline of the *S. turtur* in the UK and across Europe means that practical conservation action to attempt to reverse the population decline is urgently needed. Previous studies have identified reduced reproductive success (Browne and Aebischer 2004), probably linked to food limitation (Browne and Aebischer 2003a), as the most likely driver of the decline, but existing measures designed to provide seed food may not be appropriate or sufficiently widely adopted to benefit *S. turtur*. Here, we describe a new seed mix tailored to provide *S. turtur* with the seed and vegetation structure needed throughout its breeding season, with an emphasis on seed provision early in the breeding season when food resources are thought to be limiting (Browne and Aebischer 2003a). The trial plots provided plentiful and accessible seed early in the first breeding season. However, refinements in the seed mix and management are required to provide better foraging conditions subsequently.

During year one, no control habitat type performed consistently better in terms of seed provision and vegetation structure than autumn-sown trial plots. Habitats that had a more open vegetation structure favoured by *S. turtur* (such as fallow and wild bird cover during late June) produced less seed: indeed, no habitat produced as much seed than autumn-sown trial plots at any point during the season. However, the vegetation in autumn-sown trial plots did grow rapidly and, in many cases, was too dense to allow access by foraging *S. turtur* by late June. Indeed, mean vegetation structure was similar to known *S. turtur* foraging locations (Browne & Aebischer, 2003a) only early in Year 1. *S. turtur* were observed using some autumn-sown trial plots during our study: the foraging areas used tended to be those containing areas of bare ground and good establishment of *F. officinalis* (J. C. Dunn, unpubl. data). This is likely to be due to both seed accessibility and availability, and *S. turtur* are known to prefer relatively open areas for foraging (Browne & Aebischer, 2003a), possibly to reduce perceived predation risk (e.g. Whittingham et al., 2006). This suggests management intervention, similar to that carried out for other current AES options, on part of the trial plots would be required during June in order to alter vegetation structure to make them more attractive to foraging *S. turtur* without reducing seed availability within the trial plots. This could be done by mowing strips through each trial plot in order to allow foraging birds access to seeds, or by scarification of strips through each trial plot to create a heterogeneous mosaic. Douglas et al. (2009) suggest similar measures for improving accessibility for birds foraging for invertebrates in AE habitats during the summer months. Whilst we did not assess invertebrate abundance overall within our plots, we demonstrate elsewhere that our plots perform well in terms of attracting foraging pollinators (Dunn et al., 2013) and are thus likely to provide additional benefits for other invertebrate, and consequently avian, taxa (e.g. Moorcroft et al., 2002; Douglas et al., 2009; Dunn et al., 2010a).

Differences in establishment between sown species during year one largely correlated with differential sowing rates during the first sampling round, with the less competitive species (*F. officinalis* and *C. fontanum*) decreasing in abundance during the second and third sampling rounds, and the more competitive species (*Trifolium spp.*, *V. sativa* and *M. lupulina*) increasing. The lower establishment rates, especially of *F. officinalis*, in spring-sown trial plots, suggests that spring-sowing is unlikely to be viable for the provision of seed early in the *S. turtur* breeding season when birds return from wintering grounds and food availability is thought especially limiting (Browne & Aebischer, 2003a).

During year two, management marginally influenced the establishment of both *V. sativa* and *F. officinalis*, with more *V. sativa* in mown trial plots and more *F.*

officinalis in scarified trial plots. However, establishment of *F. officinalis* was very low overall and was, in fact, four times higher in scarified trial plots, being present at 16 % of points in scarified trial plots compared to 4 % of points in mown trial plots. Seed availability increased more between rounds, and was consistently higher on scarified trial plots than on the fallow controls; however, vegetation structure was poorer on scarified trial plots than their controls, especially during the second sampling round. This again suggests that management interventions will be required within the breeding season in order to increase the accessibility of the seed resource to foraging *S. turtur*. Scarification of part of the trial plots during March could also improve establishment during the subsequent breeding season of *F. officinalis,* which is primarily a spring germinating species benefiting from spring cultivation. No beneficial differences in terms of seed provision or vegetation structure were present between mown trial plots and their nectar flower controls. This suggests that mown trial plots performed similarly to second year nectar flower mixes, with no discernible additional benefits for *S. turtur* and indicates that autumn mowing is unlikely to be a viable management strategy for *S. turtur* trial plots, also suggesting that the benefits of mowing in terms of trial plot structure are relatively short-lived. Importantly, seed provision on all trial plots increased between years one and two, suggesting that management which promotes suitable vegetation structure for foraging will also maintain seed supply into the second year and, possibly, beyond.

During the 1960s, when the UK *S. turtur* population was increasing, the distribution of *S. turtur* was noted to be very similar to that of *F. officinalis*, suggesting a tight link between the two species (Murton et al. 1964). In the 1960s, *F. officinalis* seeds formed 35 – 60 % of *S. turtur* diet. More recently, when wheat and oil seed rape seeds were found to dominate *S. turtur* diet, *F. officinalis* remained in

12.8 % and 12.7 % of adult and nestling diets, respectively (Browne & Aebischer, 2003a), and foraging sites containing *F. officinalis* were strongly selected in proportion to their availability (Browne & Aebischer, 2003a). This leads to the question of whether *S. turtur* have a specific nutritional requirement fulfilled by *F. officinalis*, or whether this species happens to occur more frequently (alone or as part of a wider community of arable plants) in habitat structures selected by foraging *S. turtur*. *F. officinalis* has a semi-prostrate structure, with seeds being easily accessible to ground-foraging birds. It is also a poor competitor although it can become a weed in certain crop types, and tends to occur amongst relatively sparse vegetation (more often on light soils), so it may well be that the foraging habitats of *S. turtur* happen to coincide with *F. officinalis* distribution. The potential implications of nutritional differences between past and present *S. turtur* diet warrant further investigation; however, until more is known it might be prudent to assume that *F. officinalis* should remain an important component of the *S. turtur* trial plot seed mix, despite its comparative expense when compared to other components of both our trial plot mix, and of standard nectar flower mixes (current payments under HLS per hectare of nectar flower mix are £450, and is set to rise to £511 per hectare under the new Countryside Stewardship (see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/389521/Countryside_Stewardship_Rates.pdf) with standard nectar flower seed costing £145 - £197.50 per ha. The *S. turtur* trial plot mix costs £337.50 per ha when sown at 15kg / ha, due mostly to the high cost of *F. officinalis* seed). Additional management costs, estimated by one farmer on our trial plot sites to be £175 per year for topping and scarification (unpubl. data), mean that payments under the current schemes for nectar flower mixes are unlikely to cover the seed and management costs of the *S. turtur* trial plot mix.

Conclusions and management recommendations

The development of an extensive, seed-provisioning option for *S. turtur* is considered vital for the conservation of this species, where a switch in diet has occurred (Browne and Aebischer 2003a) concurrently with a reduction in breeding output sufficient to explain the population decline (Browne and Aebischer 2004). Most existing AES options are suboptimal in providing accessible food for *S. turtur* and, alone, short-term provision of seed through supplementary feeding risks the spread of parasite infection and disease (Stockdale et al., in press, Lennon et al., 2013) and they do not provide a sustainable solution for *S. turtur*.

Seed provision within our mix was greater than any control habitat types during year 1, and early in the season trial plot vegetation structure was no different from previously published data documenting the vegetation structure of *S. turtur* foraging locations. However, management intervention is required in order to maintain a favourable sward that will remain attractive to foraging *S. turtur*. The ground disturbance provided by scarification is likely to be the best way to encourage the germination of *F. officinalis* that seeds in early summer, whilst suppressing the dense growth of *Trifolium spp.* and *V. sativa* encouraged by topping, and seems the best recommendation for management of *S. turtur* trial plots into the second year. Scarification of whole (autumn) or part of the trial plots (spring / summer) may be required at multiple and various times of the year, depending on local conditions.

We recommend alterations to the seed mix composition, reducing the rates of *V. sativa* and *T. pratense* to decrease the overall vegetation height, removing *C. fontanum* from the mix entirely and reducing the sowing rate of the modified mix (10 – 15 kg/ha depending on soil type) in order to encourage a longer-lasting, open sward, although mid-season management is still likely to be necessary to keep the sward open. The addition of *Lotus corniculatus* to the mix, which has a relatively prostrate structure, may help to keep the overall vegetation structure low. The efficacy of the new mix will be trialed on six sites during 2012-14; however, this new mix was made available to selected new and existing HLS agreement holders in key hotspots for *S. turtur* in East Anglia, UK, during 2012 and 2013, as a modified nectar flower mixture (HLS option HF4), as part of *Operation Turtle Dove*. Elsewhere, we show that the *S. turtur* trial plots perform just as well, if not better, than nectar flower plots in terms of attracting foraging pollinators (Dunn et al., 2013), so the inclusion of the *S. turtur* mix as a modified nectar flower option provides only additional benefits above and beyond that provided by a standard nectar flower mix. However, further testing of this new mix is needed, along with monitoring of *S. turtur* utilizing the trial plots in order to determine whether the provision of semi-natural food resources impacts positively on *S. turtur* abundance and reproductive success. More generally, AES options should seek to address the trade-off between food abundance and accessibility through management of vegetation structure (Douglas et al., 2009; Dunn et al., 2010b).

Acknowledgements

Thanks are due to the six farmers who hosted trial plots, the six farmers whose farms acted as controls, and to Kings of Holbeach for providing and assisting with the development of the seed mix. Judit Mateos, Derek Gruar, Jenny Bright, Vivien Hartwell, Catherine Gutmann-Roberts, Jake Frost, Joanne Stonehouse and Rebecca Melville carried out fieldwork alongside JCD; Judit Mateos and Rosie Lennon assisted with seed analysis alongside JCD. This work was jointly funded by the RSPB and Natural England through the *Action for Birds in England* partnership.

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Table 1. Trial plot seed mix

Species	% weight
Common Fumitory *Fumaria officinalis*	2.88
Corvus Red Clover *Trifolium pratense*	14.3
Avoca White Clover *Trifolium repens*	14.3
Virgo Black Medick *Medicago lupulina*	14.3
Early English Common Vetch *Vicia sativa*	54.1
Common Mouse-Ear *Cerastium fontanum*	0.12

Table 2. Summary of significance levels and direction of effects (Dir), mean ± 1 SE from the raw data for habitat comparisons during year 1 in a) May, b) late June and c) late July/August, compared to autumn sown trial plots. Full model details and effect sizes can be found in Appendix B. The desired direction of effect in comparison to autumn-sown trial plots is given in brackets after each vegetation variable, and significance levels along with actual direction of effect are denoted as: (+) or (-) $p<0.1$, + or - $p<0.05$, ++ or -- $p<0.01$. Abbreviations are NF: nectar flower plots; SS trial: spring sown trial plots; WBC: wild bird cover; and FEM: floristically enhanced margins; all apart from Autumn trial and SS trial are control habitats.

2a)

	Seed availability x 100 (more)			% bare ground (more)			% vegetation cover (less)			Vegetation height (less)			Vegetation density (less)		
Habitat	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE
Autumn trial		3.62	1.04	N/A	42.28	4.02		9.67	1.94		16.68	2.37		7.63	1.42
Fallow		0.95	0.33		44.69	6.67		7.07	2.02	+	11.14	2.08	+	4.34	1.01
Grass	(+)	0.71	0.46	++	4.90	1.18	-	25.73	3.39		19.04	2.47		9.54	1.64

Meadow	0.55	0.40	+	23.04	7.60		16.29	4.13		19.71	3.64		10.00	2.30
NF	1.12	0.89	+	49.44	18.69		6.22	3.92	-	9.75	3.84	--	5.69	2.19
SS trial	0.10	0.06	-	95.48	1.46		0.56	0.37	++	0.25	0.15	++	0.29	0.29
WBC	2.24	0.86	--	83.74	4.49		4.61	1.40	++	3.16	1.09	++	1.20	0.75
FEM	2.25	2.18		40.50	5.64		9.29	2.33		12.69	2.86		5.06	1.50

2b)

	Seed availability x 100 (more)			% bare ground (more)			% vegetation cover (less)			Vegetation height (less)			Vegetation density (less)		
Habitat	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE
Autumn trial		43.34	11.41		9.53	1.69		39.70	3.15		29.21	2.62		18.28	2.02
Fallow	(+)	0.74	0.26	--	39.08	5.69	+	18.01	3.18	++	16.81	2.77	++	8.85	1.63
Grass	+	2.14	0.87		8.28	2.96	+	20.44	2.76	++	14.91	2.18	++	5.80	0.98
Meadow		0.78	0.38		17.52	6.63		23.59	4.75		25.44	4.74		11.11	2.45

NF		116.07	31.22		20.17	9.11		49.21	7.00		26.33	4.54		8.75	1.79
SS trial		0.00	0.00	--	81.89	3.95		0.80	0.51	++	1.20	0.51	++	0.27	0.18
WBC	+	20.25	8.61	--	58.76	4.21	++	10.40	2.06	++	4.29	0.82	++	1.68	0.36
FEM		12.85	10.05	-	22.71	5.31	+	13.32	3.56	++	13.59	2.29	++	7.77	1.51

2c)

	Seed availability x 100 (more)			% bare ground (more)			% vegetation cover (less)			Vegetation height (less)			Vegetation density (less)		
Habitat	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE	Direction	Mean	SE
Autumn trial		145.82	30.62		6.33	1.64		45.07	2.98		29.48	2.47		18.57	1.92
Fallow	+	14.02	5.92	--	42.00	6.01	+	13.79	2.80	++	14.33	2.34	++	5.14	1.09
Grass	++	7.17	4.08		7.07	2.42	+	21.58	3.23	++	14.82	1.97	++	5.58	1.23
Meadow		3.14	1.37		19.83	7.49		28.89	4.97		23.70	5.18		15.33	3.89
NF		16.93	7.89		11.50	4.41		43.82	6.99		19.60	3.19		5.55	1.38

SS trial	24.55	10.11		29.11	6.07		16.88	4.65	(+)	10.79	3.78	++	6.21	2.67
WBC	29.11	14.29	--	32.40	4.30		35.68	4.33		20.69	2.87	++	4.66	1.00
FEM	5.18	3.54		15.98	3.66	+	17.84	4.44		18.21	3.64	++	7.25	1.31

Table 3. Results of t-tests comparing a) vegetation height and b) % bare ground on trial plots during 5 surveys with that of known *S. turtur* foraging locations (from Browne & Aebischer, 2003a). Trial plot structure not differing significantly from foraging site structure is highlighted in bold.

a)

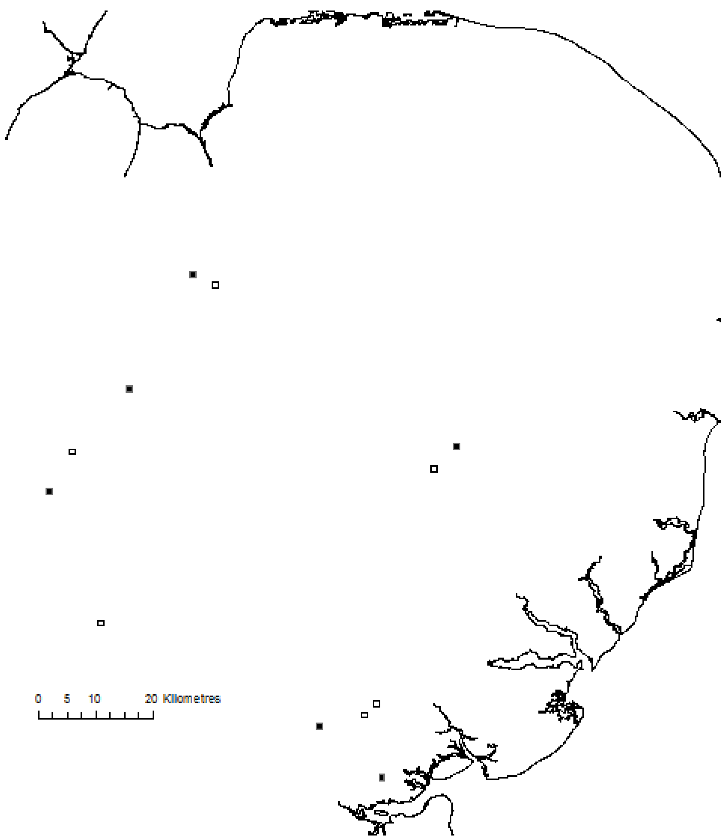
Vegetation height	Year 1			Year 2 topped		Year 2 scarified	
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 1	Round 2
t	**1.102**	5.027	4.635	3.620	7.558	**1.888**	9.292
df	**134**	134	130	124	123	**126**	126
p	**0.274**	<0.001	<0.001	<0.001	<0.001	**0.061**	<0.001

b)

% bare ground	Year 1			Year 2 topped		Year 2 scarified	
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 1	Round 2
t	**1.450**	4.871	4.752	4.224	4.143	4.097	4.672
df	**134**	134	130	124	123	126	126
p	**0.149**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Figure 1. a) A map showing locations of trial and control farms within the UK, with trial plot farms shown as black boxes and control farms as white boxes (© Crown Copyright. All rights reserved. RSPB licence 100021787) and b) a schematic diagram showing our sampling design within plots. Numbers of trial and control plots varied between farms (mean ± 1 SE plots: trial: 5.67 ± 0.4; control year 1: 5.5 ± 0.34; control year 2: 3.0 ± 0.4)

a)



b)

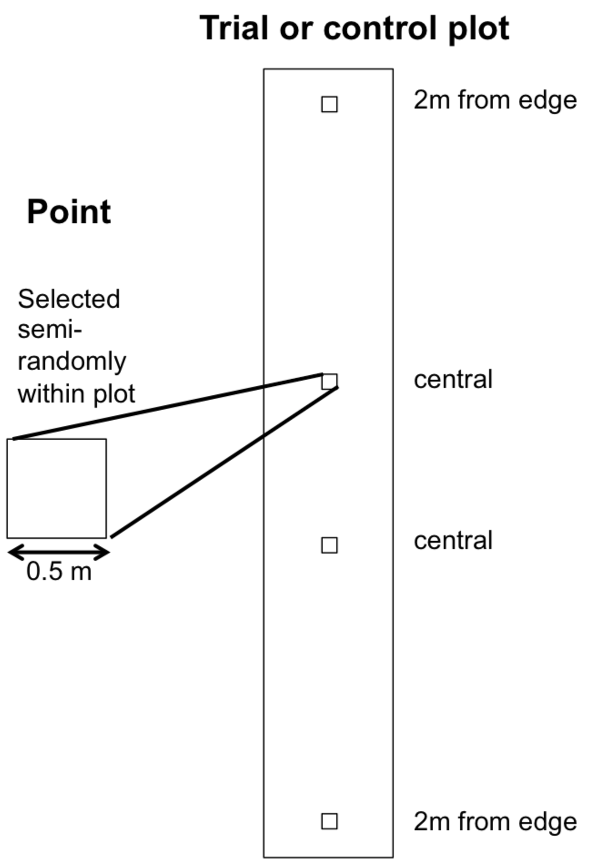

Trial or control plot
2m from edge
Point
Selected semi-randomly within plot
central
central
0.5 m
2m from edge

Figure 2. Establishment of trial plot species (proportion of plots within which each species was detected) according to sowing date (autumn or spring) during May, early July and late July/August of year one. Bars depict mean ± 1 SE from the raw data. * above a line indicates a significant effect of round only at p<0.05; x above a line indicates a significant effects of an interaction between round and sowing date at p<0.05. Sowing date alone did not significantly affect the establishment of any trial plot species; full model results and estimates are available in Appendix 2.

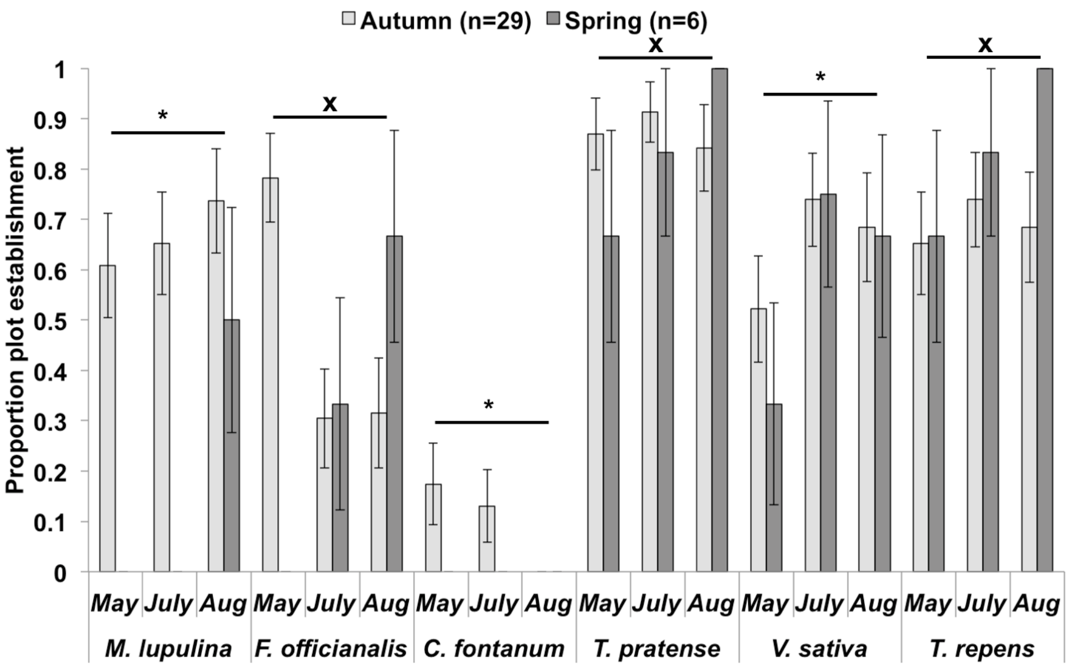


Figure 3. Establishment of each species (proportion of plots within which each species was detected) in Rounds 1 or 2 in mown or scarified trial plots during Year two. Bars depict mean ± 1 SE from the raw data. * above a line indicates a significant effect of round only at p<0.05; ^ above a line indicates a near significant effect of management at p<0.1. Interactions between round and management did not significantly affect the establishment of any trial plot species; full model results and estimates are available in Appendix 3.

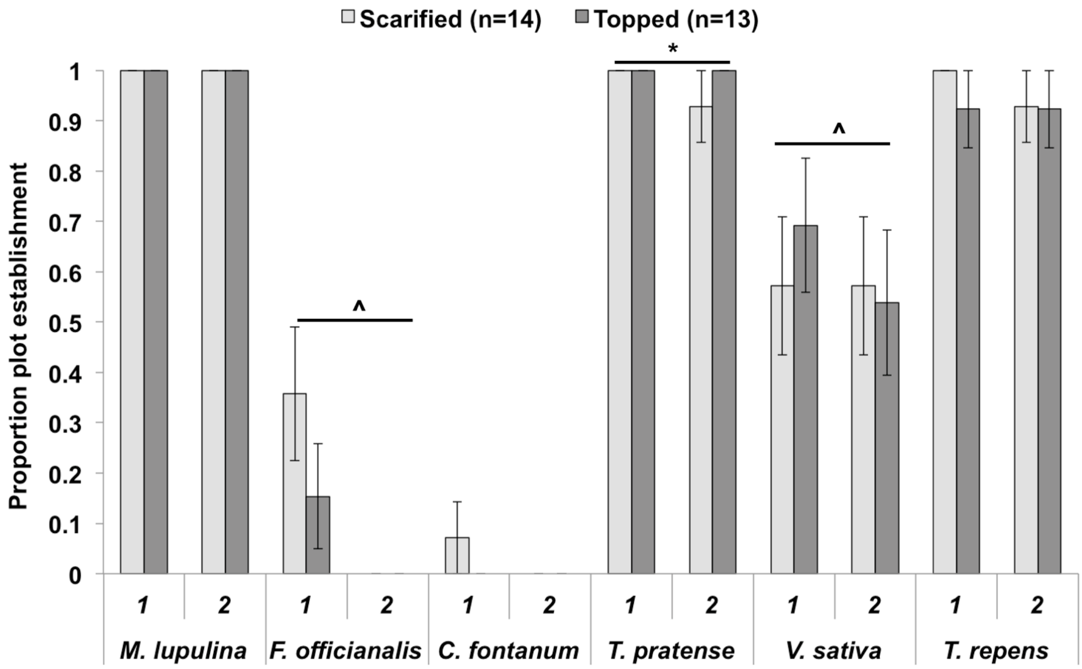
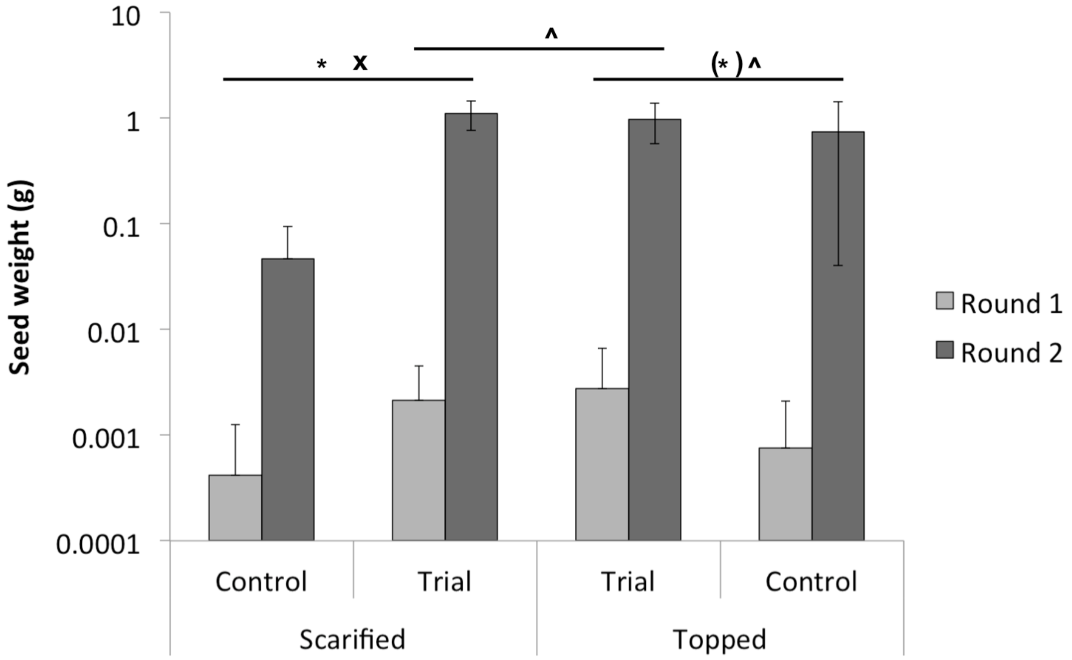
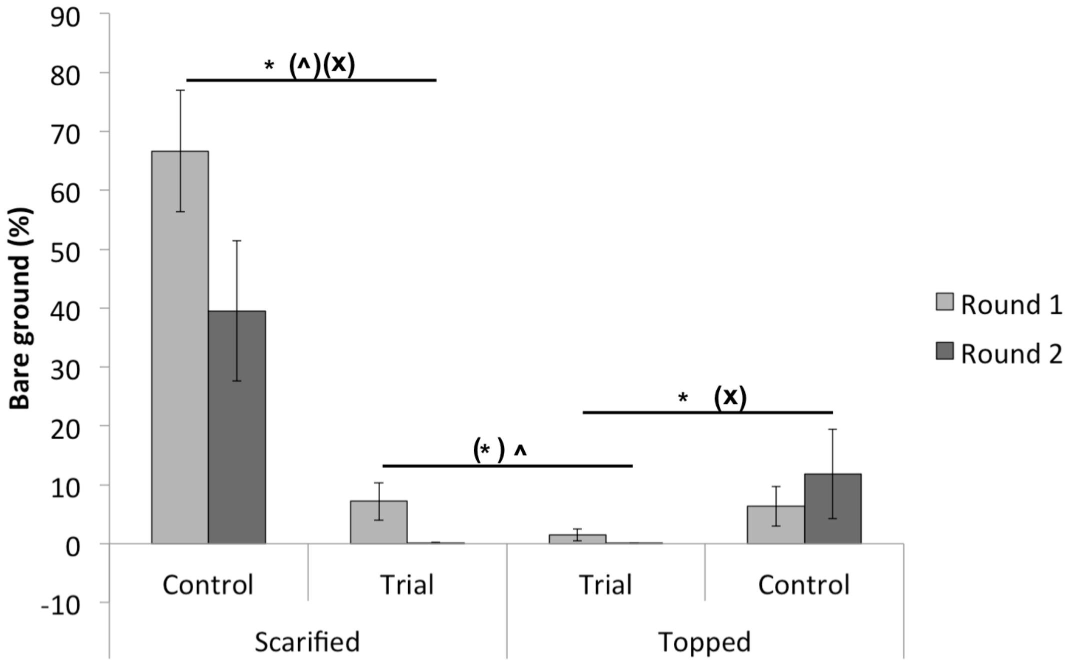


Figure 4. Mean ± 1 SE (A) Seed weight, (B) Bare ground, (C) Vegetation cover, (D) Vegetation height and (E) Vegetation density in different trial and control plots during year 2 from the raw data. Note log y-axis for 4(A). Significant differences at $p<0.05$ are demonstrated by symbols above lines: * denotes an effect of habitat; ^ denotes an effect of round and x denotes a significant Habitat x Round interaction. Near significant differences (<0.1) are denoted by the same symbols in parentheses. Full model results and estimates are given in Appendix E.

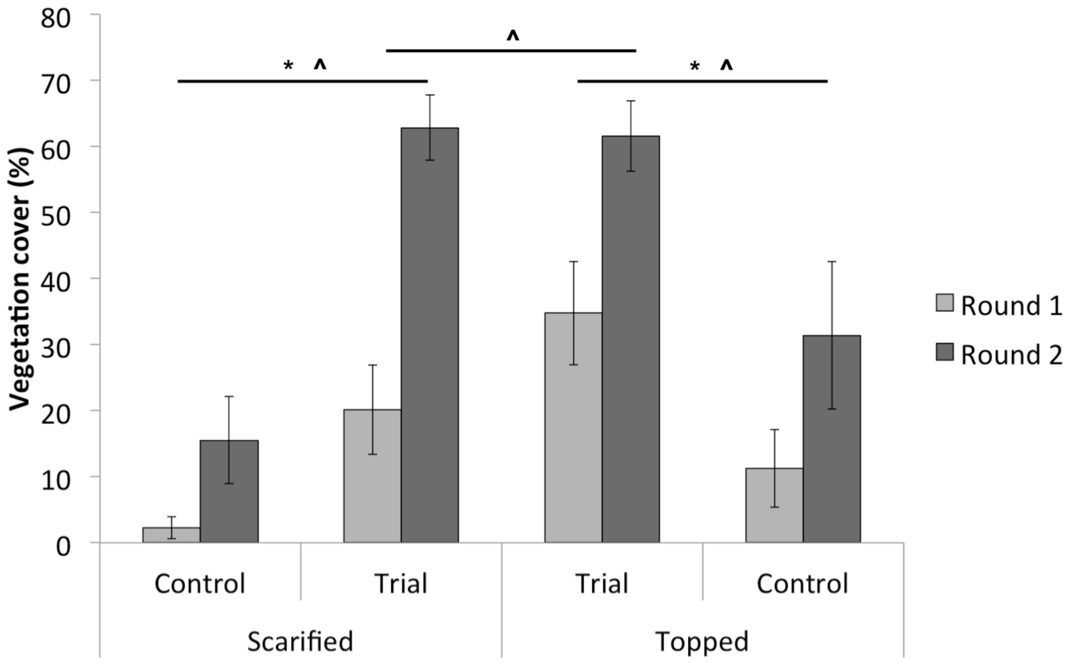
4(A) Seed weight



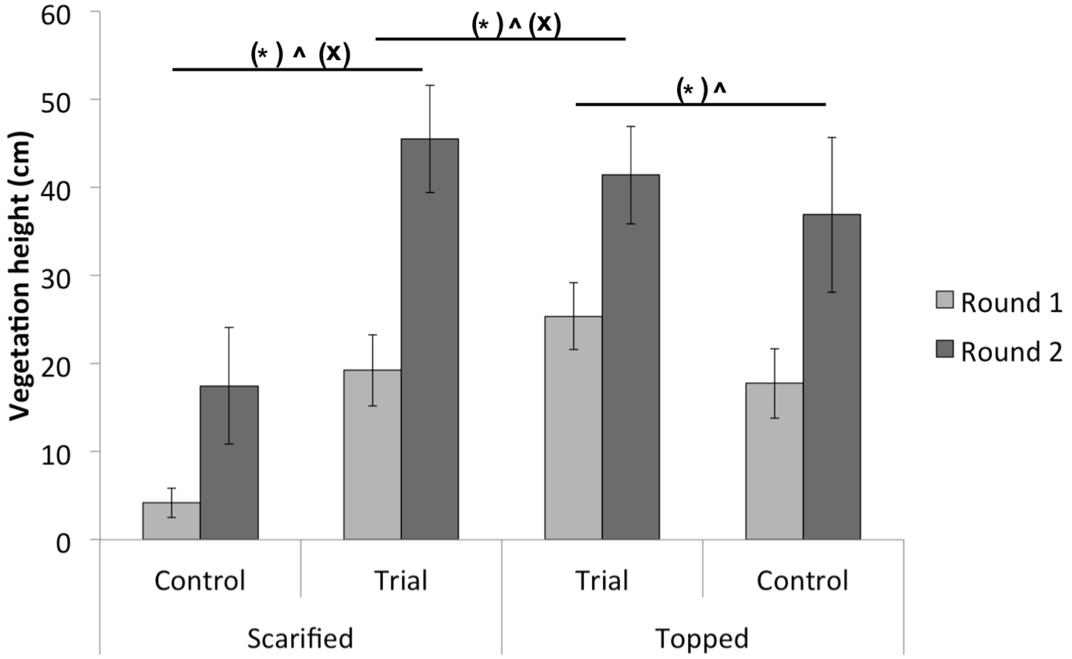
4(B) Bare ground



4(C) Vegetation cover



4(D) Vegetation height



4(E) Vegetation density

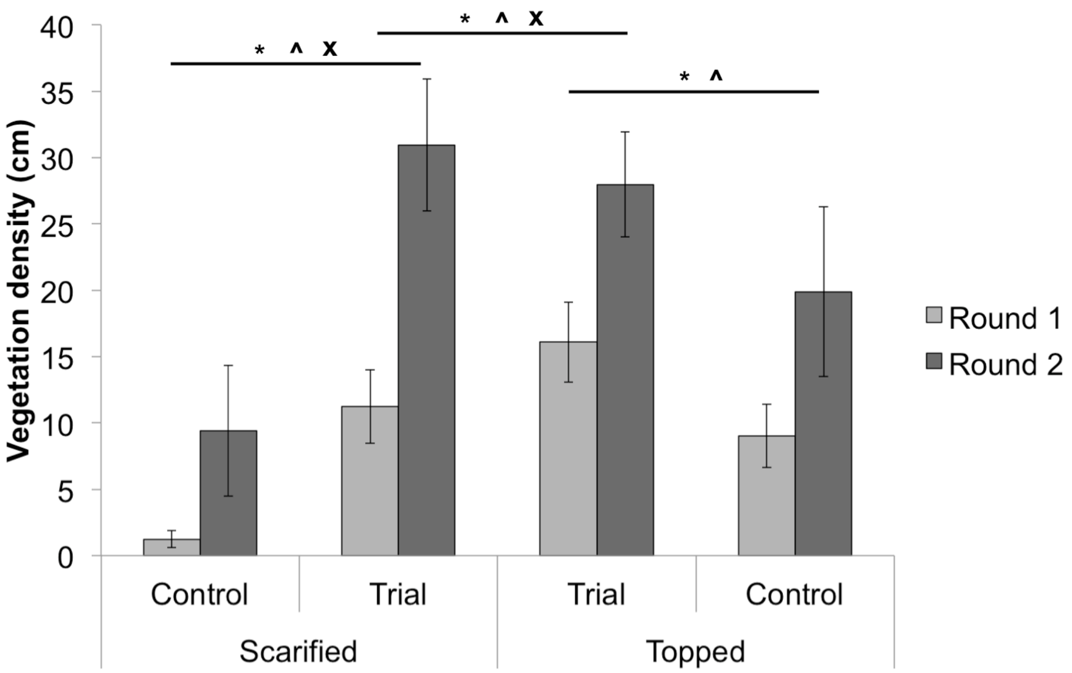
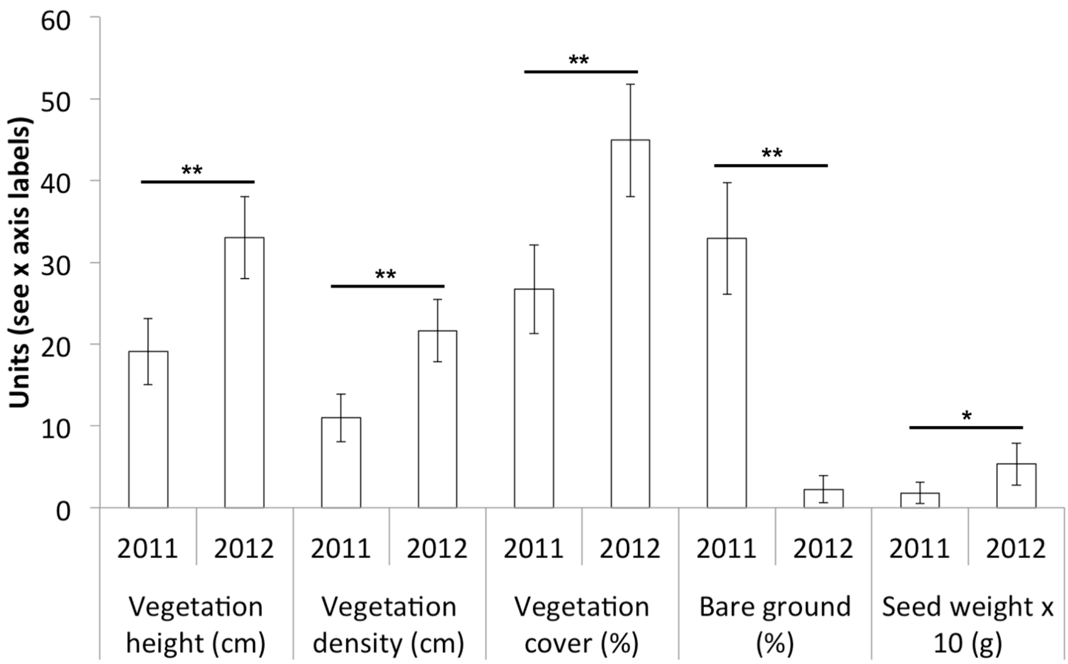


Figure 5. Mean vegetation and seed parameters on trial plots during Year 1 (2011) and Year 2 (2012). Between-year significance is denoted by * (p<0.05) and ** (p<0.01).



Appendix A. Seeds considered important in *S. turtur* diet, taken from Murton et al. (1964) and Browne & Aebischer (2003a).

Murton et al. (1964)	**Browne & Aebischer (2003a)**
Brassica *Sinapsis spp.*	Wheat *Triticum aestivum var*
Chickweed *Stellaria media*	Oil seed rape *Brassica napus var*
Knotgrass *Polygonum sp.*	Chickweed *Stellaria media*
Fumitory *Fumaria spp.*	Mignonette *Reseda lutea*
Grass spp. (*Agropyron spp.* and *Festuca spp.*)	Knotgrass *Polygonum aviculare*
Cereals (specifically Wheat and Oil seed rape)	Redshank *Persicaria maculosa*
Creeping buttercup *Ranunculus repens*	Fumitory *Fumaria officinalis*
Wild mignonette *Reseda lutea*	Grass *Graminae spp.*

Heartsease *Viola tricolor*

White campion *Silene alba*

Bladder campion *Silene vulgaris*

Common mouse-ear *Cerastium holosteoides*

Stitchwort spp. *Stellaria spp.*

Corn spurrey *Spergula arvensis*

Fat hen *Chenopodium album*

Orache *Atriplex patula*

Black medick *Medicago spp.*

Clover spp. *Trifolium spp.*

Spurge spp. *Euphorbia spp.*

Field pansy *Viola arvensis*

Orache *Atriplex patula*

Nettle *Urtica dioica*

Dock *Rumex spp.*

Scarlet pimpernel *Anagallis arvensis*

Round-leaf fluellen *Kickxia spuria*

Goosegrass *Galium aparine*

Stinking chamomile *Anthemis cotula*

Appendix B. a) Results and b) estimates from GLMMs determining the independent and interactive influences of Round (May, early July or late July/August) and Sowing date (autumn or spring) on the establishment of each trial plot species during Year 1.

2a								**Trial plot species**										
	V. sativa			*M. lupulina*			*F. officinalis*			*C. fontanum*			*T. pratense*			*T. repens*		
Variable	**χ^2**	**df**	**p**	**χ^2**	**df**	**p**	**χ^2**	**df**	**P**	**χ^2**	**df**	**p**	**χ^2**	**df**	**p**	**χ^2**	**df**	**p**
Round	42.07	2	<0.001	6.75	2	0.034	15.30	2	<0.001	18.68	2	<0.001	6.08	2	0.048	27.14	2	<0.001
Sowing date	0.16	1	0.691	3.00	1	0.083	2.33	1	0.127	2.32	1	0.128	0.10	1	0.755	0.01	1	0.948
Sowing date x Round	4.20	2	0.123	- [a]	- [a]	- [a]	21.84	2	<0.001	- [a]	- [a]	- [a]	19.79	2	<0.001	8.31	2	0.016

[a] '-' indicates that the model didn't converge owing to a lack of establishment in spring sown trial plots.

2b

Trial plot species

	V. sativa		*M. lupulina*		*F. officinalis*		*C. fontanum*		*T. pratense*		*T. repens*	
Variable	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Intercept	-0.41	1.05	-0.41	0.58	-1.99	0.36	-5.82	1.08	0.27	0.55	1.00	0.98
Round (May) [a]	-2.57	0.45	-0.06	0.34	1.47	0.38	1.46	0.73	0.57	0.35	-1.49	0.46
Round (July) [a]	-0.54	0.36	0.77	0.35	-0.55	0.50	* [b]	* [b]	0.50	0.37	-0.34	0.51
Sowing date (Spring)	-	-	-2.57	1.32	-0.69	0.94	-	-	0.21	1.26	-0.49	2.28
Sowing date (Spring) x Round (May)	-	-	-	-	* [b]	* [b]	-	-	-2.59	0.83	-0.66	0.92

Sowing date (Spring) x Round (July)	-	-	-	-	1.96	1.05	-	-	1.21	0.87	2.15	0.96

[a] Estimates for Round are compared to Round 2 (June).

[b] “*” indicates a lack of variation in this category, leading to unreliable estimates.

Appendix C. a) Results and b) Estimates from GLMMs determining the independent and interactive influences of Round (May or July) and Management (mown or scarified) on the establishment of each trial plot species during Year 2.

4a	*V. sativa*			*M. lupulina*			*F. officinalis*			*C. fontanum*			*T. pratense*			*T. repens*		
Variable	**χ^2/z**	**df**	**p**	**χ^2/z**	**df**	**p**	**χ^2/z**	**df**	**p**	**χ^2/z**	**df**	**p**	**χ^2/z**	**df**	**p**	**χ^2/z**	**df**	**p**
Round	1.717	1	0.190	0.729	1	0.393	- [a]	- [a]	- [a]	1.600	1	0.206	23.222	1	<0.001	1.767	1	0.184
Management	3.070	1	0.080	0.099	1	0.753	3.241	1	0.072	0.263	1	0.608	1.487	1	0.223	0.305	1	0.581
Management x Round	0.367	1	0.544	0.810	1	0.368	- [a]	- [a]	- [a]	- [a]	- [a]	- [a]	0.511	1	0.475	0.696	1	0.404

[a] '-' indicates that the model didn't converge owing to a lack of establishment in July. b) Estimates for significant terms in a).

4b	*V. sativa*		*M. lupulina*		*F. officinalis*		*C. fontanum*		*T. pratense*		*T. repens*	
Variable	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Intercept	-1.689	0.979	-	-	-2.651	0.511	-	-	**5.077**	0.931	-	-
Round	-	-	-	-	-	-	-	-	**-2.050**	0.494	-	-
Management (Mown)	0.713	0.400	-	-	-1.445	0.821	-	-	-	-	-	-
Management x Round	-	-	-	-	-	-	-	-	-	-	-	-

Appendix D. Results of GLMMs comparing a) seed availability, b) % bare ground, c) % vegetation cover, d) vegetation height and e) vegetation density between trial plots and alternative habitat during each survey in year 1. The first row in the table shows the important of the habitat term in the GLMM (with χ^2 statistics), the rest of the table shows the significance of post-hoc contrasts comparing each specified habitat type with autumn sown trial plots (z statistics); habitats significantly different from autumn sown trial plots are denoted in bold. '-' indicates that the sample size for this term during this time period was too small to give meaningful estimates

2a			**May**					**Late June/early July**					**Late July/August**		
Habitat	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Overall significance	N/A	N/A	9.96	7	0.191	N/A	N/A	26.741	7	<0.001	N/A	N/A	20.189	7	0.005
Fallow	-1.217	0.827	-1.473	7	0.141	-4.038	2.426	-1.664	7	0.096	-1.983	0.837	**-2.370**	**7**	**0.018**
Grass	-1.703	0.936	-1.819	7	0.069	-2.994	1.389	**-2.155**	**7**	**0.031**	-2.673	0.877	**-3.048**	**7**	**0.002**

Meadow	-0.739	0.908	-0.815	7	0.415	-3.989	3.217	-1.240	7	0.215	-3.423	2.088	-1.639	7	0.101
Nectar flower	-1.182	1.947	-0.607	7	0.544	0.498	1.084	0.459	7	0.646	-1.089	1.007	-1.082	7	0.279
Spring sown trial plots	-3.504	2.828	-1.239	7	0.215	-	-	-0.007	7	0.994	-0.544	1.210	-0.450	7	0.653
Wild bird cover	-0.391	0.642	-0.609	7	0.543	-1.371	0.670	**-2.047**	**7**	**0.041**	-0.653	0.623	-1.048	7	0.294
Floristically enhanced margins	-0.928	0.956	-0.971	7	0.332	-1.374	0.953	-1.441	7	0.150	-2.560	1.598	-1.602	7	0.109

2b			**May**					**Late June/early July**					**Late July/August**		
Habitat	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Overall significance	N/A	N/A	93.867	7	<0.001	N/A	N/A	52.264	7	<0.001	N/A	N/A	32.854	7	<0.001

Fallow	0.513	0.445	1.153	7	0.249	1.960	0.540	**3.633**	**7**	**<0.001**	2.412	0.636	**3.794**	**7**	**<0.001**
Grass	-2.120	0.547	**-3.876**	**7**	**<0.001**	-0.145	0.653	-0.222	7	0.824	-0.089	0.770	-0.116	7	0.908
Meadow	-1.305	0.600	**-2.177**	**7**	**0.029**	0.451	0.704	0.641	7	0.522	0.670	0.777	0.863	7	0.388
Nectar flower	-1.665	0.700	**-2.379**	**7**	**0.017**	-0.057	0.838	-0.068	7	0.946	0.250	0.959	0.261	7	0.794
Spring sown trial plots	2.740	1.103	**2.485**	**7**	**0.013**	2.912	0.734	**3.966**	**7**	**<0.001**	0.725	0.804	0.902	7	0.367
Wild bird cover	1.503	0.448	**3.357**	**7**	**<0.001**	1.968	0.489	**4.019**	**7**	**<0.001**	1.739	0.621	**2.800**	**7**	**0.005**
Floristically enhanced margins	0.561	0.568	0.988	7	0.323	1.787	0.756	**2.365**	**7**	**0.018**	**1.273**	0.849	1.500	7	0.134

2c	**May**	**Late June/early July**	**Late July/August**

Habitat	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Overall significance	N/A	N/A	15.33	7	0.032	N/A	N/A	29.991	7	<0.001	N/A	N/A	15.326	7	0.032
Fallow	-0.342	0.733	-0.466	7	0.641	-1.030	0.470	**-2.193**	**7**	**0.028**	-1.282	0.520	**-2.467**	**7**	**0.014**
Grass	1.746	0.540	**2.176**	**7**	**0.030**	-1.053	0.437	**-2.412**	**7**	**0.016**	-1.118	0.439	**-2.546**	**7**	**0.011**
Meadow	0.598	0.705	0.849	7	0.396	-0.733	0.533	-1.375	7	0.169	-0.573	0.553	-1.036	7	0.300
Nectar flower	-0.479	1.528	-0.313	7	0.754	0.376	0.531	0.708	7	0.479	0.001	0.553	0.001	7	0.999
Spring sown trial plots	-2.952	2.780	-1.062	7	0.288	-4.064	2.197	-1.849	7	0.064	-1.210	0.670	-1.805	7	0.071
Wild bird cover	-0.794	0.841	-0.944	7	0.345	-1.648	0.485	**-3.398**	**7**	**<0.001**	-0.191	0.390	-0.490	7	0.624
Floristically enhanced margins	-0.044	0.828	-0.053	7	0.958	-1.625	0.656	**-2.479**	**7**	**0.013**	-1.317	0.612	**-2.153**	**7**	**0.031**

2d		May				Late June/early July					Late July/August				
Habitat	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Overall significance	N/A	N/A	79.792	7	<0.001	N/A	N/A	83.526	7	<0.001	N/A	N/A	15.794	7	0.027
Fallow	-0.271	0.118	**-2.289**	**7**	**0.022**	-0.410	0.105	**-3.816**	**7**	**<0.001**	**-0.302**	**0.105**	**-2.868**	**7**	**0.004**
Grass	0.058	0.101	0.575	7	0.565	-0.434	0.098	**-4.412**	**7**	**<0.001**	**-0.264**	**0.098**	**-2.678**	**7**	**0.007**
Meadow	0.107	0.119	0.898	7	0.369	-0.123	0.112	-1.093	7	0.274	-0.090	0.112	-0.801	7	0.423
Nectar flower	0.380	0.127	**2.990**	**7**	**0.003**	0.168	0.123	1.369	7	0.171	0.033	0.130	0.258	7	0.797
Spring sown trial plots	-0.989	0.214	**-4.631**	**7**	**<0.001**	-0.902	0.204	**-4.411**	**7**	**<0.001**	-0.286	0.152	-1.875	7	0.061
Wild bird cover	-0.563	0.117	**-4.797**	**7**	**<0.001**	-0.676	0.108	**-6.273**	**7**	**<0.001**	-0.064	0.088	-0.730	7	0.465

Floristically enhanced margins	-0.091	0.137	-0.661	7	0.508	-0.532	0.131	**-4.077**	**7**	**<0.001**	-0.172	0.135	-1.271	7	0.204

2e			**May**					**Late June/early July**					**Late July/August**		
Habitat	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Overall significance	N/A	N/A	88.374	7	<0.001	N/A	N/A	61.731	7	<0.001	N/A	N/A	45.042	7	<0.001
Fallow	-0.479	0.205	**-2.334**	**7**	**0.020**	-0.570	0.165	**-3.465**	**7**	**<0.001**	-0.881	0.177	**-4.984**	**7**	**<0.001**
Grass	0.080	0.166	0.485	7	0.628	-0.669	0.157	**-4.268**	**7**	**<0.001**	-0.752	0.164	**-4.601**	**7**	**<0.001**
Meadow	0.166	0.189	0.878	7	0.380	-0.189	0.176	-1.069	7	0.285	-0.223	0.173	-1.291	7	0.197
Nectar flower	0.551	0.195	**2.823**	**7**	**0.005**	0.029	0.198	0.147	7	0.883	-0.306	0.231	-1.326	7	0.185

Spring sown trial plots	-2.557	0.721	**-3.545**	**7**	**<0.001**	-1.719	0.583	**-2.949**	**7**	**0.003**	-0.542	0.272	**-1.996**	**7**	**0.046**
Wild bird cover	-1.291	0.249	**-5.178**	**7**	**<0.001**	-1.127	0.195	**-5.786**	**7**	**<0.001**	-0.733	0.160	**-4.586**	**7**	**<0.001**
Floristically enhanced margins	-0.155	0.228	-0.678	7	0.498	-0.533	0.190	**-2.797**	**7**	**0.005**	-0.526	0.214	**-2.454**	**7**	**0.014**

Appendix E. Results of GLMMs determining the influence of habitat management and sampling round on a) Seed abundance, b) % bare ground, c) % vegetation cover, d) vegetation height and e) vegetation density during year 2. Raw data are displayed for significant trends in Figures 3a, 3b and 3c. Estimates are given for significant terms (shown in bold) considered to influence the response variable. For non-significant variables, values presented are χ^2 statistics comparing the models with and without the relevant term; for significant variables, z values are presented.

5a) Seed abundance

	Mown trial vs. scarified trial					**Mown trial vs. nectar flower**					**Scarified trial vs. fallow**				
	Estimate	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Habitat			0.819	1	0.366			1.684	1	0.092			0.069	1	0.793
Round	4.113	0.847	4.855	1	<0.001	4.180	1.190	3.513	1	<0.001	2.337	0.589	3.970	1	<0.001
Habitat x Round			0.001	1	0.992			0.001	1	0.978	4.024	1.053	3.822	1	<0.001

5b) % Bare ground

	Mown trial vs. scarified trial					Mown trial vs. nectar flower					Scarified trial vs. fallow				
	Estimate	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Habitat	-1.255	0.672	-1.868	1	0.062	-1.909	0.718	-2.658	1	0.008	-1.719	0.354	-4.855	1	<0.001
Round	-3.135	1.368	-2.293	1	0.022			0.012	1	0.914			-1.747	1	0.081
Habitat x Round			0.034	1	0.854			3.1	1	0.078			-1.690	1	0.091

5c) Vegetation cover

	Mown trial vs. scarified trial					Mown trial vs. nectar flower					Scarified trial vs. fallow				
	Estimate	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**

Habitat			0.494	1	0.482	0.603	0.221	2.728	1	0.006	1.132	0.283	4.002	1	<0.001
Round	0.695	0.174	3.994	1	<0.001	0.524	0.205	2.553	1	0.011	0.957	0.238	4.018	1	0.001
Habitat x Round			1.340	1	0.247			0.613	1	0.474			0.213	1	0.645

5d) Vegetation height

	Mown trial vs. scarified trial					**Mown trial vs. nectar flower**					**Scarified trial vs. fallow**				
	Estimate	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Habitat	0.163	0.092	1.771	1	0.077	0.125	0.073	1.711	1	0.087	1.017	0.181	5.626	1	<0.001
Round	0.480	0.084	5.683	1	<0.001	0.298	0.068	4.397	1	<0.001	0.793	0.168	4.711	1	<0.001
Habitat x Round	-0.207	0.119	-1.739	1	0.082			0.617	1	0.432	-0.313	0.188	-1.664	1	0.096

5e) Vegetation density

	Mown trial vs. scarified trial					Mown trial vs. nectar flower					Scarified trial vs. fallow				
	Estimate	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**	**Estimate**	**SE**	**χ^2/z**	**df**	**p**
Habitat	0.252	0.106	2.376	1	0.018	0.269	0.085	3.150	1	0.002	1.466	0.232	6.334	1	<0.001
Round	0.596	0.097	6.122	1	<0.001	0.318	0.078	4.102	1	<0.001	1.193	0.233	5.121	1	<0.001
Habitat x Round	-0.287	0.135	-2.123	1	0.034			0.177	1	0.674	-0.598	0.253	-2.367	1	0.018